

September 14, 1972

MEMORANDUM

TO: Marvin Miura, OEQC

FROM: Doak C. Cox

ENVIRONMENTAL ASPECTS OF PROPOSED
SEWAGE TREATMENT AND INJECTION WELL DISPOSAL
FOR THE KAHULUI-WAILUKU SYSTEM, MAUI

Summary and conclusions

1. It is our opinion that the proposed underground disposal of effluent from the secondary sewage treatment plant to be constructed makai of Kanaha Pond will have no significant effect on the water quality or ecology of the Pond.

2. We believe that the proposed system of secondary treatment and underground disposal at the site under consideration may be the optimal system considering all economic and environmental aspects. However, the inadequate understanding of the hydrogeology of the area indicated in the planning documents leads us to question whether the decision in favor of the proposed system is based on as sound and comprehensive an analysis as it merits.

3. The underground trajectory of the major part of the effluent projected in the planning documents is erroneous, and the area of its emergence in the ocean will be much shallower and closer to shore than is indicated in the documents.

4. The primary environmental concern with the proposed injection scheme should be with the influence of the effluent on the quality of the coastal waters and on their ecology.

5. In our opinion, the effect of the effluent on the water quality of the Maui Electric wells will be negligible.

6. A buoyancy effect appears to have been overlooked in the analysis of the capacity of the disposal wells. The effects of the oversight are an underestimate of the injection head and of the margin of excess capacity required to compensate for plugging effects.

7. The adequacy of proposed protection against tsunami by a 6-ft. land fill is questionable.

Introduction

As you requested 17 July we have reviewed the Maui County plans for secondary treatment of sewage from the combined Kahului and Wailuku systems at a proposed plant makai of Kanaha Pond and for underground disposal of the effluent through injection wells. Although you requested a special focus in our review on possible effects of the effluent on Kanaha Pond, some other possible environmental problems surfaced in the course of our general review of the plans for background.

The following have contributed to our review:

Doak C. Cox, Director, Environmental Center

Gordon Dugan, Associate Professor of Civil Engineering and
Water Resources Research Center

Jerry Johnson, Assistant Director, Environmental Center and
Associate Professor, School of Public Health

Frank Peterson, Associate Professor, Department of Geology and
Geophysics and Water Resources Research Center

Our review has encompassed the reports listed below as well as others cited in the list of references:

R. M. Towill Corp.: "Sewerage master plan for County of Maui", 1971.

J. M. Montgomery: "Study of wastewater treatment and disposal for Wailuku-Kahului", 1971.

J. M. Montgomery: "Results of a pilot test on an injection well for the Wailuku-Kahului waste reclamation facilities", 1972.

Maui Chapter, Conservation Council for Hawaii report: "Kanaha Pond pilot injection well test", June 1972.

R. C. Scott: "Preliminary geohydrologic evaluation of Kahului injection well field" [May 1972].

Wastewater to be treated and disposed of

The discussion in the wastewater report (Montgomery, 1971) of the quantity and character of the wastewater to be handled in the Kahului-Wailuku system, although not necessarily serious in error as to conclusions, contains some statements that indicate unfamiliarity of the authors with the actual situation on Maui.

Water supply for the area is stated (p. II-1) to be from surface sources and from "Maui-type" wells. An analysis from the Mokuahau tank is given as representative of surface water and an analysis from the Iao Tunnel as representative of a Maui well supply. The Mokuahau tank is fed from drilled basal groundwater wells, not from surface water. The Iao Tunnel is a tunnel tapping high-level dike groundwater not a Maui well in basal groundwater. Surface water is not ordinarily used in the Wailuku-Kahului water system, although surface water may be used in the Paia-Kuau part of the system.

Measurements of flows in the Kahului system are plotted (fig. 3) and discussed (pp. II-4, 5) in relation to infiltration. It is concluded (fig. 3) that there is a steady infiltration of about 1.4 mgd and variable sewage flows resulting in a total having a normal range from 1.43 to 2.00 mgd. The measurements in fig. 3 suggest a semi-diurnal periodicity of the infiltration, which is to be expected because it is derived from groundwater which is subject to tidal changes in head. A portion of the variation in total flow could be attributed in part to infiltration rather than variation of the wastewater flow.

As will be shown later, the density of the combined flow is of critical importance to the behavior of the effluent when injected after treatment. The densities are not reported, but the total dissolved-solid contents reported, 766 mg/l for Kahului and 530 mg/l for Wailuku (Montgomery, 1971, p. II-5) suggest that in spite of the infiltration of brackish water, the flows have densities much closer to that of fresh water than that of sea water.

Geohydrology

General geology

An understanding of the geology of the north coast of the Maui Isthmus is essential to the understanding of the groundwater hydrology of the area and to the results of injecting effluent from a sewage treatment plant on that coast, as proposed. As recognized in the planning documents for the sewage disposal system (Montgomery, 1971, 1972), the bedrock of the area is lava flows of Haleakala. These lava flows, predominantly aa flows of the Kula series, tend to be thicker than normal in the vicinity of Kahului because of their ponding in the Isthmus against the east flank of the West Maui volcano (Stearns and Macdonald, 1942; USGS, 1970). The lavas are overlain by coastal-plain sediments, including sand, silt, beach rock, and coral, and offshore by a coral reef.

Well and test hole drilling in the last several years has provided a good deal of detailed information as to the thickness, character, and distribution of the coastal-plain sediments. However, we are not aware of any major disagreements between the results of this drilling and the geologic model of the area portrayed by the earlier reports as claimed in the planning documents (Montgomery, 1971, p. IV-4).

Geology at test well

To indicate both geology and injection capacity, a 385-ft. test well was drilled at proposed site of the sewage treatment plant and injection well field at an altitude of about 9 ft. The well was cased from the surface to a depth of 180 ft. (171 ft. below sea level) and left open below.

The log of this test well (Montgomery, 1972, table 1) indicates that fresh bedrock lavas were reached 51 ft. below sea level. Most of the section above that depth was composed of sand, beach gravel, and coral, although a 4-ft. layer of residual soil capping the lavas appears to have been encountered. The remainder of the hole, extending to 376 ft. below sea level, passed through volcanic rocks.

Many layers of "cinders" and "ash" were reported which were interpreted in the report as pyroclastics, the author apparently not realizing the tendency of local drillers to report clinkers as "cinders." The drilling method is not indicated in the report, but the Kanaha Pond Committee (1972) reports initial trial use of reverse circulation suggesting that the drilling was done by rotary methods. The 5ft./hr. rate of penetration reported for one of the "cinder" beds (118 to 144 ft. depth) seems far too low for a rotary drilling rate in cinders and tends to confirm that the material is clinker.

The log reported some coral and shell fragments to depths as great as 260 ft. Although it is possible that some marine sediments might be interbedded with the Haleakala lava flows, it seems more likely that the samples were contaminated with material from higher in the hole, as can readily occur in rotary drilling and as seems suggested by the fact that the coral and shell fragments especially at the lower depths are reported to be associated with hard basalt rather than "cinders."

Thus the log seems to indicate just what should have been expected, a series of lava flows of the Kula series of Haleakala, capped by a thin residual soil and a section of dune, beach and coral reef sediments, perhaps a little thicker than one would expect on the basis of surface exposures.

Geohydrology

The test well report indicates a considerable lack of understanding of the hydrology of Herzberg lenses and of the salt water beneath them under Hawaiian conditions, and the effects of the lack are aggravated by the geologic misinterpretation already discussed.

The salinity in the test well was reported to remain essentially constant (1,700 to 1,800 mg/l Cl^- ; 3.5 mhos/cm) from 15 to 65 ft. depth (6 to 59 ft. below sea level); to increase below that to essentially sea water salinity (16 mhos/cm) at a depth of 130 ft. (121 ft. below sea level), and to continue essentially constant below that depth (Montgomery, 1972, p. 3). The brackish water encountered in the upper part of the well is unquestionably that of the Herzberg lens of the Maui Isthmus, floating on and displacing sea water in the bedrock aquifer; and the zone of increasing salinity represent the zone of mixture of fresh and salt water at the base of the lens.

After the well had been cased, the head in the lower, open section, was reported to have had a range of 1.4 ft. under static conditions, from -1.4 to 0.0 ft. msl (Montgomery, 1972, table II). The range is readily explicable as that due to tidal oscillation, but the low value is somewhat surprising and leads to questions as to the validity of the measurement or of the datum. Although times of measurement were reported there were insufficient measurements to establish the pattern of the tidal oscillation.

No measurements of the head in the brackish water of the Herzberg lens were reported. The head expectable in the vicinity of the well is about 2 1/2 ft. which is reasonably consistent with the depth range reported for the zone of mixture. ($2\frac{1}{2} \times 40$ (Herzberg factor) = 100 ft. depth below msl for middle of Herzberg lens.)

Four shallow piezometer tubes installed in the vicinity of the test well indicated heads in the ground water in the sediments ranging from +1.69 to +2.94 under static conditions. Again measurements were insufficient to portray the tidal oscillation, and hence mean heads cannot be determined. A seaward gradient of 10.4 ft./mi. was reported on the basis of the piezometer tube readings (Montgomery, 1972, fig. 6). Although this is perhaps reasonable, it cannot be accepted as accurate without determination of the mean heads, and in any case it is misleading, because the mean gradient over the first mile from the coast cannot exceed about 3 ft/mi.

The geohydrology model indicated from background knowledge and the results of the test wells is sketched in fig. 1.

On the basis that the proposed injection of effluent from the sewage treatment plant will occur in the uncased zone of the test well and 3 additional similar wells, between 180 ft. and 385 ft. below the surface, and on the basis of an estimated $1/2^\circ$ seaward dip of the lavas in this zone, the test-well report concludes (Montgomery, 1972, p. 6) that: "... injected water can migrate offshore throughout a distance of several miles. The effluent should spread over a large area, be naturally filtered, and be dispersed within salt-water bearing formations. Throughout the course of the migration, the wastewater should lose its identity in a vast body of saline formation water, and be harmlessly dispensed into the ocean medium."

Two misconceptions are embodied in these conclusions. First, the effluent will not in any significant way be confined to the particular lava horizon in which it is injected. Second, the buoyancy of the effluent in the salt water cannot be neglected.

The permeability of the lava flows is probably higher in the plane of their strike and dip than it is transverse to that plane. The ratio of the two permeabilities is not known. However, the transverse permeability is so great that in a section of normal lava flows on the flank of a Hawaiian volcano essentially horizontal flow is freely possible, and indeed the existence of the characteristic Herzberg lenses close to sea level in which the discharge seaward occurs essentially horizontally, across the lava flows, indicates that their non-isotropicity does not result in any severe distortion.

As shown in the section on wastewater, the density of the water to be treated and injected will be much less than that of sea water and may approach that of fresh water. In consequence of the combination of low density and transverse permeability, after injection into the aquifer around the injection zone of the effluent wells, the effluent will tend to rise toward the Herzberg lens because of its buoyancy in the salt water. As it disperses outward from the wells and rises, the effluent will mix with salt water and the density of the mixture will become greater than that of the original effluent, though still significantly lower than the density of the salt water. The mixed effluent

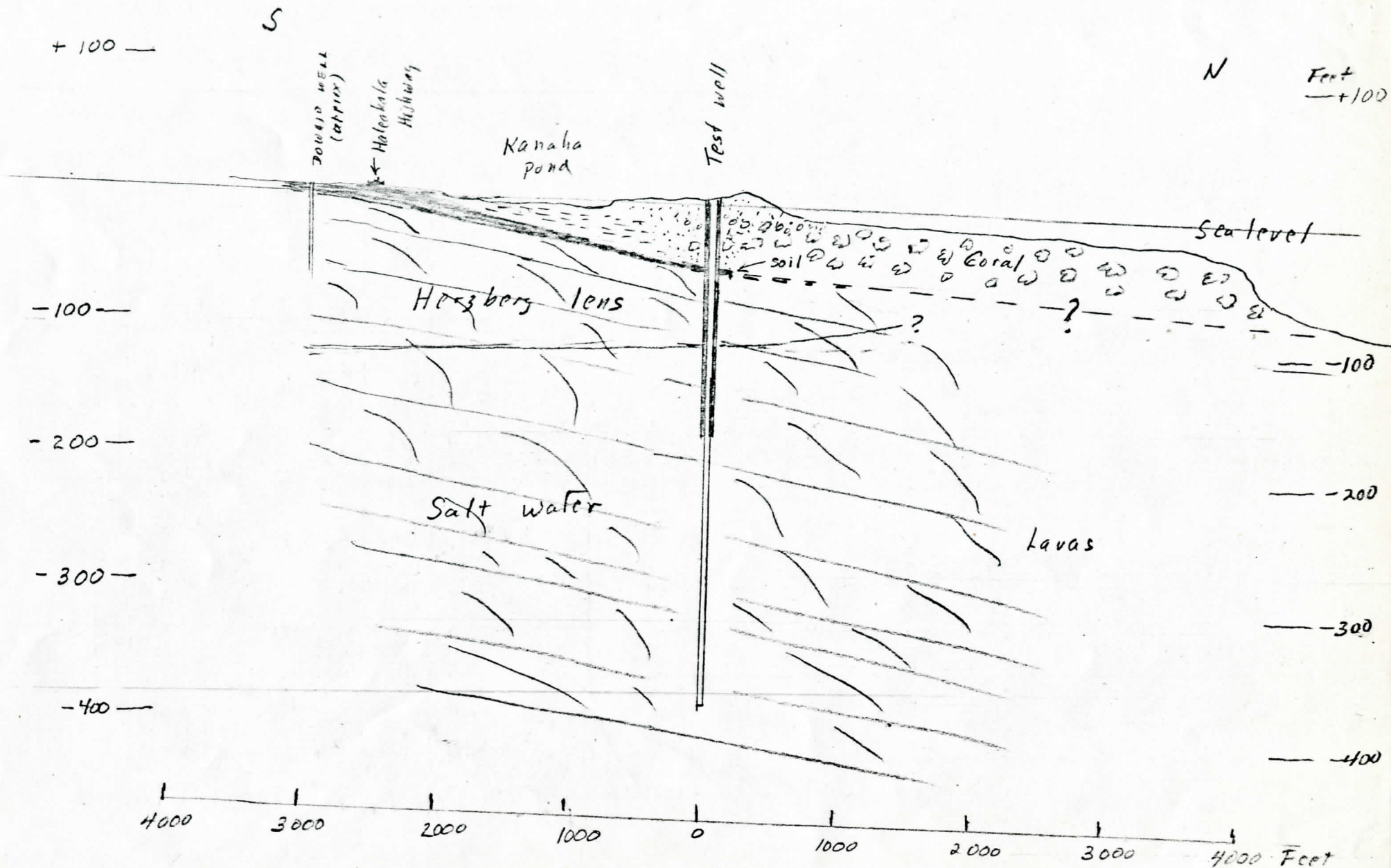


Figure 1. Sketch hydrogeologic profile through test well

will, therefore, rise into the lower part of the Herzberg lens as sketched in figure 2, though the particular horizon of the Herzberg lens in which it will have neutral buoyancy is uncertain. Most of the effluent will then tend to move seaward as does the rest of the water in the Herzberg lens. Some, diluting the salt water only slightly, may perhaps move landward in the counter current in the salt water beneath the lens which compensates for the salt water entrainment in the seaward moving zone of mixture at the bottom of the lens.

The exact direction of natural seaward flow of the lower part of the Herzberg lens in the vicinity of the prepared injection wells is uncertain because the effectiveness of the caprock of sediments over the basalt aquifer is uncertain. The natural direction may be significantly modified by the draft from the wells Maui Electric Co. uses for cooling water although these wells draw mainly on the salt water. It will also be modified somewhat by draft from the DOWALD well drilled to supply water to Kanaha Pond during drought periods. Hence parts of the effluent may get drawn to these wells, though as will be shown later, these parts are unlikely to be of great significance.

Most of the effluent will probably be discharged to the ocean wherever the natural discharge of the lower part of the Herzberg lens discharges. This discharge cannot take place at a depth much greater than that of the Herzberg lens at the well, about 100 ft. below sea level at the middle of the zone of mixture. Whether this discharge will mainly take place a) directly seaward beyond the outer margin of the reef, b) directly seaward by leakage through the reef, or c) diverted toward Spreckelsville, depends significantly on the integrity of the residual soil layer below sea level, about which we know very little. The chance that the main discharge into the ocean will occur several miles at sea, as postulated in the test well report, is negligible.

Injection-well tests

Draft test

The draft test of the injection test well provided results, summarized below, that at first appear straightforward:

<u>Draft Rate</u> <u>gpm</u>	<u>Duration</u>		<u>Water Level</u>	<u>Drawdown</u>	<u>Spec. Cap.</u>
	<u>hr.</u>	<u>min.</u>	<u>ft. msl.</u>	<u>ft.</u>	<u>gpm/ft.</u>
0	(initial W.l.)		+0.20	0.00	
4,000	1	35	-1.38	1.58	2,540
6,000	1	30	-2.13	2.33	2,570
8,000	1	30	-3.38	3.58	2,730
10,000	1	55	-4.55	4.75	2,100

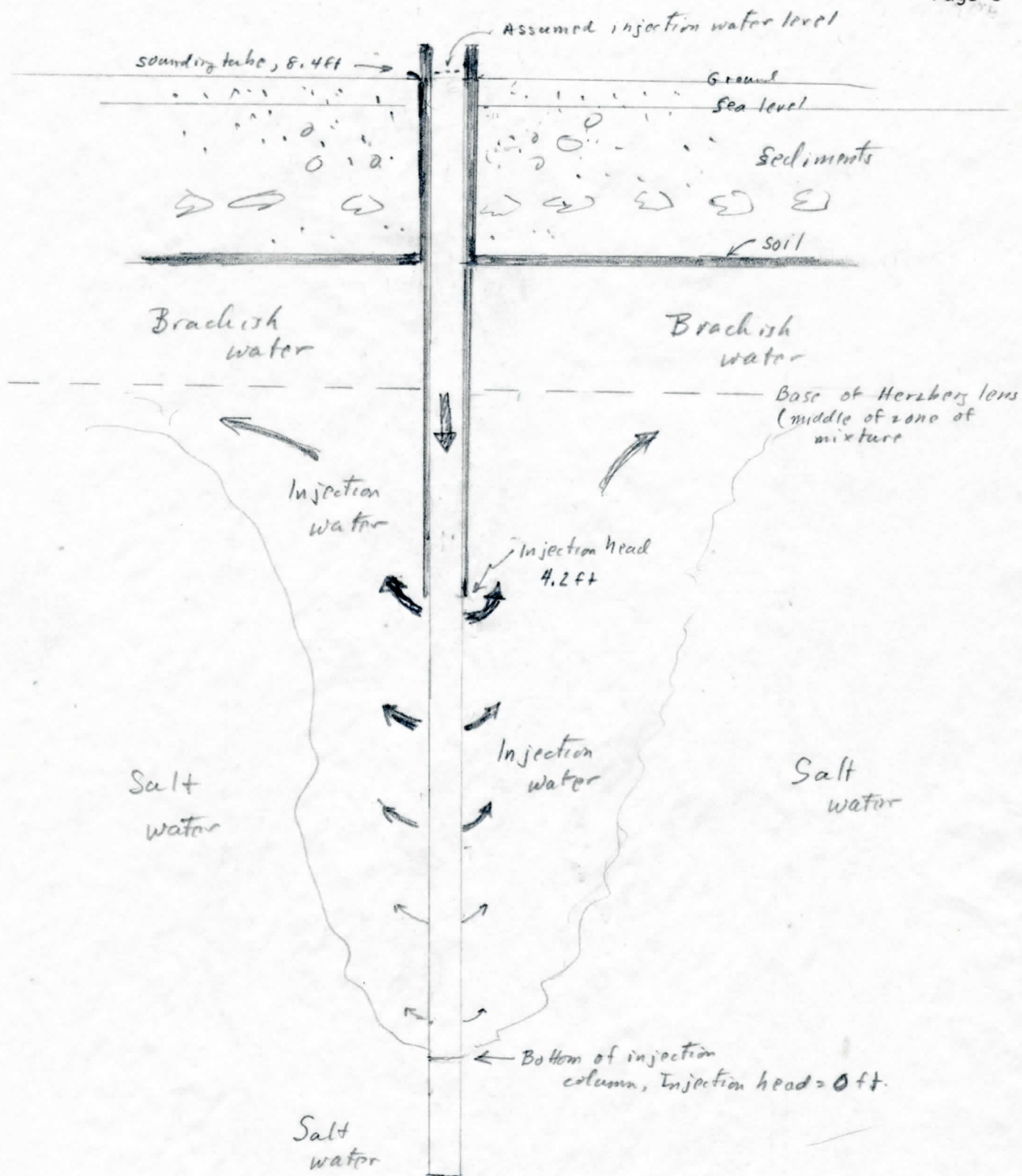


Figure 2. Sketch of flow of injection water toward Herzberg lens

The apparent increase in specific capacity with increase in draft from 4,000 to 6,000 gpm is suspicious, but the decrease in specific capacity at higher rates of draft is expectable. It should be noted, however, that no tidal observations were made prior to the pumping test and the times of pumping at any single rate were insufficient to disclose tidal changes in drawdown level. Since the tide range in the bedrock aquifer at the test-hole site might well exceed 1 foot, and the duration of the pump test was equivalent to about a half semidiurnal tide period or a quarter diurnal tide period, the quantitative significance of the pump test results must be regarded as doubtful.

The observations on the piezometric tube, installed near the well but penetrating sediments only, indicated only that there is little connection between the aquifer in the sediments and that in the bedrock.

Injection test

Results of low-rate recharge testing were without value because of the effects of air entrainment. The results of high-rate recharge testing are in complete disagreement with those of the pump test, as shown by the following table:

<u>Draft Rate</u> <u>gpm</u>	<u>Duration</u> <u>hr. min.</u>	<u>Water Level</u> <u>ft. msl.</u>	<u>Buildup</u> <u>ft. #</u>	<u>Spec. Cap.</u> <u>gpm/ft.</u>
0	initial W.l.	-0.14	0.00	1.1
2,900	3 00	+2.5 av.*	2.6 av.*	1,100*
5,800	4 00	+0.22 av.*	0.36 av.	16,100
5,900?	2 00	+0.93 av.*	1.07 av.*	5,500*
0	final W.l.	-0.09	0.05	

*Unreliable because of air entrainment

#Based on initial, not final, water level

It may be noted that an apparent tidal change in the water level in the sediment piezometers is shown by a drop in water levels while the recharge of the basal aquifer was continuing at maximum rate. The apparent tidal amplitude is, however, very small, and the water level records in the piezometers indicate mainly, again, the separation between the bedrock aquifer and the sediments.

Because of the doubt arising from the discrepant results of the draft and injection tests the only reliable information that these tests can be considered to provide is that the specific yield of the test well is high. How high, quantitatively, is not reliably indicated.

Reconciliation of draft and injection tests

Other than gross mistakes, two possible causes for the discrepancy between the results of the draft test and those of the infiltration test seem worthy of examination.

a) The velocities in the well are sufficient to produce Pitot effects on the water level measuring tube. The effect with injection (downward flow) would have been to lower the apparent water level, decrease the apparent buildup and increase the apparent specific capacity. However, the effect with draft (upward flow) would have been to increase the apparent water level, decrease the apparent drawdown, and again increase the apparent specific capacity. Hence this explanation seems unlikely to be valid.

b) Tidal changes during the tests lowered the static water level during the draft test so that the actual drawdowns were less than those calculated, and the specific capacities therefore greater than calculated, and raised the static water level during the injection test so that the buildups were greater than those calculated and the specific capacities therefore less than calculated. If this explanation is valid, the specific capacities calculated from the draft test may be conservative. Considering that a ground-water tide range much greater than about 1-1/4 ft. is unlikely at the test well site, an extremely conservative specific capacity may be calculated by adding a maximum 1.25 ft. tidal correction to the 4.75 ft. drawdown for 10,000 gpm draft. The specific capacity would then be at least 1,700 gpm/ft.

Translation of the test results to the transmissibility of the aquifer is meaningless, not only because of the quantitative unreliability of the test results but because transmissibility has no significance in an aquifer which does not have a determined and limited depth.

A final caution must be noted. The water drawn from the test well during the draft test was salt water and the water injected in the injection test was also salt water. If the water injected had been fresh, a greater head will be required for injection than would be calculated from the rate of injection and specific capacity. If the sewage effluent to be injected is essentially fresh, the head necessary merely to displace the salt water to the bottom of the casing would be about 4.2 feet. The head necessary to displace the salt water to the bottom of the well would be about 9.4 ft. Simplistically, the static head required for displacement should be added to the dynamic buildup calculated from the rate of injection and specific capacity. In actuality, the dynamic head available for injection will not be uniform with depth but decrease with increasing depth and increasing height of the column of fresh water above the level of injection. If the total fresh-water injection head is limited to the elevation top of the water level sounding tube above sea level, 8.4 ft., and if the density of the injected water were essentially that of fresh water, the injected water column would extend only to a depth of about 336 ft. below sea level, leaving about 41 ft. at the bottom of the well, occupied by salt water. The head available for injection would range from about 4.2 feet at the bottom of the casing to zero at the bottom of the injected-water column. This situation is sketched in figure 2. If the density of the injected water

equalled the average of fresh water and sea water densities, the injected water column would reach the bottom of the well, the head available for injection would range from about 6.3 ft. at the bottom of the casing to about 3.7 ft. at the bottom of the well and the average head available for injection would be about 5.0 ft.

Fluorescein test

Although the fluorescein test was justified as a cheap means of indicating possible direct connections between the injection zone and the sea or pond, the lack of observation of visual effects signifies essentially nothing. A simple calculation will indicate why. If the injection were carried out at a steady rate of 6000 gpm for the full 9 hours of the test (an exaggeration), the total injection would have been 3 million gallons. The dye was dissolved in this volume, probably not uniformly. Assuming 10% porosity the volume of rock invaded would be $4 \times 10^6 \text{ ft.}^3$. If the invasion extended uniformly in all directions from the open portion of the well, the invaded zone would be a cylinder with hemispherical terminations, having a radius of only 70 ft. Even though mixing would increase somewhat the maximum penetration, it is unlikely that any significant portion of the dye would even reach the base of the sediments, 120 feet above the open portion of the well, let alone the shoreline, another 50 ft. higher and 200 ft. distant horizontally.

Expectable effects of effluent injection

Effects on Kanaha Pond

The Maui chapter of the Conservation Council for Hawaii has criticized the proposed location of the sewage treatment plant and underground injection of effluent, through four wells similar to the test well, on the basis that the effluent would reach and deleteriously affect Kanaha Pond (Kanaha Pond Committee, 1972). However, significant effects on the Pond seem very unlikely.

Although the effluent will not be confined to the particular stratigraphic horizon in which it is injected, as postulated in the test well report (Montgomery, 1972) but will rise to the lower part of the Herzberg lens spread horizontally so as to lie, in part, beneath the Pond, much of the thickness of the Herzberg lens will separate the effluent from the Pond (the entire thickness of water having a lower density than the mixture of effluent and salt water). Although the pond may be fed from its mauka edge by seepage from the Herzberg lens in the lavas, any such seepage must be derived from the uppermost part of the lens. It seems very unlikely that any significant part of the effluent can reach the pond by this means.

Using the most conservative estimate of specific capacity for an injection well, assuming that the entire 6 mgd of effluent (8640 gpm) were injected in a single well, and assuming that the density of the effluent were the average of fresh and sea-water densities, the injection water level would be at ground level, the injection head would average 5 ft., and the maximum injection head

at the bottom of the well casing would be 6.3 ft. The head would decrease very rapidly in the aquifer away from the open portion of the well, so that even at the bottom of the Herzberg lens it would be less than a foot.

The only way in which there is a significant chance of effluent reaching the pond would be via the DOWALD well which, according to Scott (1972) is about 3000 ft. mauka of the injection wells. Without knowing much more about the hydraulic gradients, it is impossible to predict quantitatively, the amount of effluent that will reach the DOWALD well. The fraction of effluent in the total well draft will, however, be extremely small. Even if significant amounts of effluent reached the pond, it is very doubtful if they would have significant effects on the pond ecology.

Effects on Maui Electric wells

Scott (1972) has recommended that the effluent-injection wells be located makai of the airport rather than at the proposed site on the basis that flow from the injection wells to the cooling water wells of Maui Electric Co., and thence to the ocean, will short-circuit the discharge of the effluent to the ocean via the natural ground-water route. In our opinion Scott has been misled by the erroneous hydrogeologic model portrayed in the Montgomery reports (1971, 1972).

First, there is a flaw in the hydraulic analysis, even if the differential densities are neglected. The only possible base for an assumed hydraulic gradient of 20 ft/mi. over the assumed 1/2 mile between the injection wells and the draft wells is a possible differential head of 10 ft. between the injection level in the first and the drawdown level in the second. Assuming through flow, however, the head about each well would not vary linearly but logarithmically, the gradient being very steep about each well but flattening with distance. In a region with through flow there might well be no flow at all between the two sets of wells as indicated by the sketch in figure 3. The sketch is simplified in that it shows only one injection and one draft well, but the total differential head between the two wells, when operating, is equal to the head drop for equal distance for the through flow normal to the line between the two wells. There is no flow from the injection well to the draft well.

Although Scott did not make explicit his assumption as to where the effluent would emerge in the ocean without the Maui Electric draft, we believe he may have accepted the Montgomery conclusion that the area of emergence would be several miles at sea, rather than over or at the toe of the reef.

Third, in his hydraulic analysis, Scott failed to take account of the effects of the multiple-density flow system. As pointed out in earlier sections, most of the effluent will rise, in the immediate vicinity of the injection wells to the lower, brackish part of the Herzberg lens. Some of the effluent may remain mixed with salt water, resulting in only slight freshening of the water beneath the lens, but this admixture will be slight. The Maui Electric wells are cased through the lens so that they draw essentially on the underlying salt water. There may be some drawdown of brackish water from the lens into

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the well, but the salinity of the water indicates the entrainment of brackish water is very slight. Hence the Maui Electric wells draw essentially from a different body of water than that in which the effluent will principally flow.

We conclude that the entrainment of effluent from the injection wells in the draft of the Maui Electric wells will be very slight, and further that such entrainment will not greatly shorten the route of the effluent to the ocean.

Effects on coastal water

Dilution of the well-injected effluent will begin where the effluent is first forced out of the wells and into the aquifer and rises in the aquifer, because of its buoyancy, to the lower part of the Herzberg lens. Since in the vicinity of an injection well the radial component of hydraulic gradient associated with the injection will be much greater than the natural component of through flow, the effluent will tend, in this vicinity to a symmetrical radial dispersal. Only at some distance from the well will the natural seaward gradient exceed the artificial components, and the flow will be essentially seaward. Thus, even from a single injection well, it seems likely that the effluent will be probably dispersed in the seaward flowing groundwater over an east-west width of at least a few hundred feet and perhaps several thousand feet. The density distribution introduced by the mixing process will probably result in dispersal over a depth of flow of at least a few tens of feet.

Tidal oscillations will result in still more dispersal as the effluent is carried in the general groundwater flow toward the ocean.

As indicated in the section on geohydrology most of the ground-water diluted effluent will emerge in the ocean at depths certainly not much greater than 100 feet and hence at no great distance from shore. The location of the area of emergence is uncertain. Not enough is known about the head distribution in the lens, in the vicinity of the injection wells, to indicate the flow pattern on the lower part of the Herzberg lens in which the effluent will be incorporated, and not enough is known about the integrity of the aquiclude that is constituted by the residual soil capping the basalt-lava aquifer beneath the overlying coral to predict the flow pattern.

If leakage through the residual soil is sufficiently great, the principal emergence of the effluent into the ocean may be through the coral reef directly seaward of the injection-well field. If it is sufficiently small, the principal emergence may be in the vicinity of the toe of the reef directly seaward. If it is sufficiently small in the vicinity of the injection well field but sufficiently great farther west, the principal emergence may be through the reef somewhere off the airport. No matter where the principal emergence occurs, there will be considerable dilution before emergence, and most of the emergence will occur by diffuse seepage over a large area rather than concentrated at a point.

Additional dilution will occur rapidly in the area of emergence into the ocean, where Herschler and Randolph (1962) have found, by dye-patch tracing a westerly current velocity of 15 ft/min.

Quantitative estimation of the initial dilution of the effluent in this ground water and the further dilution in the immediate area of emergence in the ocean is at this point impossible. Considering the possible ranges of such dilution the diluted effluent might conceivably contain nutrient concentrations several times natural ocean concentrations or only a small fraction of such concentrations.

The effects of the diluted effluent in the sea water do not seem likely to be significant. However, in the light of the great concern over meeting coastal water quality standards, the assumption of insignificant coastal water quality effects implicit in the recommendation of underground injection is an indication of an "out of sight, out of mind" philosophy which has been stimulated by the restriction of the standards to surface and coastal waters, excluding ground water.

Depths of injection wells

From the discussion of the hydraulics of injection of low-density waste water into salt water beneath a Herzberg lens, a question should be raised as to the effectiveness of the total depth and casing depth of the test well. Apart from the increment of mixing resulting from the rise of the injected water through the salt water, there appears to be little reason to extend the casing below the depth in the Herzberg lens at which the density of the water in the lens equals that of the water to be injected. There is certainly no reason to drill the well deeper than the injected water will displace sea water considering the design injection head at the surface.

The situation would be different if the waste water were to be injected below an aquiclude, but none is likely to be present at the Kahului waste water disposal plant.

Tsunami hazard

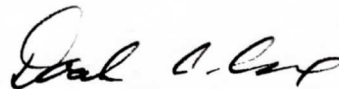
The wastewater report (Montgomery, 1971) recognizes that there is a tsunami hazard at the proposed site of the sewage treatment plant and injection wells. For comparison of costs associated with the use and other sites, the report assumes that protection will be provided by raising the plant 6 feet. Assuming a present ground level of 9 feet, this implies a raised ground-level elevation of 15 feet above mean sea level.

Records of recent tsunamis (Shephard et al, 1950; and records on file at Hawaii Institute of Geophysics) indicate tsunami runup heights in the vicinity of the proposed plant site of 22 ft. in 1946, 15 ft. in 1957, 10 ft. in 1960, and 12 ft. in 1964. There was a 24-ft. runup in 1946 at Papaula Point in Spreckelsville, 1-1/2 mi. east of the proposed plant site, and a 15-ft. runup height in 1960 at Paukukalo, west of the Kahului Breakwater. The area at

Kahului inundated by the 1946 tsunami was not mapped. However, the area inundated by the 1960 tsunami was mapped and found greater than that estimated from the standard criteria for potential tsunami inundation in Hawaii (Cox, 1961). Hence special treatment was given to the establishment of the potential tsunami inundation area at Kahului that serves as a guide to evacuation.

The normal criteria for estimating potential runup height would lead to an estimate of about 35 ft. height at the site of the proposed sewage treatment plant if there were a cliff immediately mauka of it. Because there is no cliff, the estimate could be lessened by the effects of the lowland mauka, but it should be increased because of the unusual tsunami response at Kahului. No satisfactory means exists for balancing the two effects. Hence, a 35-foot potential tsunami runup height at the plant site appears not unreasonable.

The 1946 and 1960 tsunamis were extraordinary ones. The record of tsunami at Hilo indicates that these two were the highest in the period from 1837 to date. Hence the recurrence interval of such tsunamis seems to be in excess of 50 years. The appropriate design height for the sewage treatment and disposal facilities depends upon the nature of the extent of damage would result from inundation and the degree to which such damage could be prevented by flood-proofing. For example, pump motors which would be shorted out can be protected by high walls or covered shelters. Tanks can be built to withstand the wave impact. The proposed 15-ft. msl raised ground elevation for the plant appears to provide inadequate protection against tsunamis at the proposed site unless a considerable amount of flood proofing is to be provided in the construction.



Doak C. Cox, Director

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J. Johnson
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W. Gorter, Chairman, E.C. Policy Comm.
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